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EFFECT OF BANDING SULFUR ON NURSURY TREE PRODUCTION AND QUALITY AT THE ALBUQUERQUE FOREST TREE NURSURY

PRESENTED TO
ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
FT. COLLINS, COLORADO

PREPARED BY
METRIC CORPORATION
ALBUQUERQUE, NEW MEXICO

FEBRUARY, 1985

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EFFECT OF BANDING SULFUR ON NURSURY TREE PRODUCTION AND QUALITY AT THE ALBUQUERQUE FOREST TREE NURSURY

The conventional method of lowering pH in alkaline soils involves the replacement of the base cations, primarily calcium, magnesium, sodium, and to a lesser extent potassium from the clay exchange sites with an acid or an acid forming material. Lowering the soil pH is advantageous in increasing essential nutient availability and soil fertility improvement, provided sufficient leaching occurs to carry the replaced basic cations through the soil profile.

A common practice of reducing salt buildup and pH control in agricultural soils has been accomplished with the use of sulfur. Elemental sulfur is the most economical and effective material used to reduce soil pH in forest tree nursuries (Mizell, 1980). Soils with high soluble salt concentrations have responded to elemental sulfur treatments, resulting in increases in the hydrogen ion concentrations (Samuels, 1927; and Li and Caldwell, 1966) and increased soil fertility.

Elemental S is made available to plants by oxidation to the sulfate ion ($SO_4^=$). In arable soils, only a small amount of the inorganic S occurs in states other than $SO_4^=$ (Starkey, 1966). This transformation to the $SO_4^=$ ion in soils occurs by various chemical and biochemical processes, however, the oxidation to sulfate and ultimately to sulfuric acid (H_2SO_4) is accomplished largely by the sulfur oxidizing bacteria of the genus *Thiobacillus* (Alexander, 1961; Starkey, 1950 and 1966). In the biological oxidation of sulfur, the general reactions that occur are as follows:

$$2S + 3O_2 \longrightarrow 2SO_3$$

$$2SO_3 + H_2O \rightarrow H_2SO_4$$

It is generally assumed that the sulfur bacteria are responsible for oxidation of most of the inorganic sulfur in soils. Principally, these organisms are autotrophic, motile, gram negative, short rods (Salle, 1961) that can use sulfur and incompletely oxidized inorganic sulfur compounds as specific hydrogen donors for the assimilation of carbon dioxide (CO_2). In addition, heterotrophic bacteria, actinomycites, and filamentous fungi play a minor role in the oxidation processes (Starkey, 1966).

The oxidation of elemental S increases the solubilization of soil nutrients. The sulfuric acid formed reacts with minerals and other insoluble complexes, leading to nutrient mobilization. Research by Mortvedt et. al., (1972) reported increased availability of soluble phosphate, potassium, calcium, manganese, aluminum, and magnesium from the oxidation to H_2SO_4 by inorganic S. The results of Williams and Steinberg (1959) indicated that adsorbed sulfate provided a readily available source of S for the growth of oats in pot cultures. Growth of sweetgum and green ash increased as a response of supplying sulfur with nitrogen fertilizer applications (Stone, 1980). Mullin (1969) observed that the weight of red pine seedlings was increased an average of 28 percent by applications of 1499 lb./ac. of elemental S.

The effectiveness of sulfur amendments in altering soil pH are dependent upon such factors as type of soil and particle size and placement of the amendment. Research performed by Attoe and Olson (1966) and Tisdale and Nelson (1966) reported maximum oxidation of S occurring in fine textured soils, partially as a result of the reduced leaching losses through the profile. The data of Bertramson et. al. (1950); Li and Caldwell (1966); and Tisdale and Nelson (1966) have concluded

that particle size of the applied amendment exhibited a very pronounced effect on the rate of oxidation of elemental S, with the smaller particle size yielding a more rapid rate and amount of material oxidized (McGeorge, 1945).

The relative buffering capacities of alkaline soils are a major consideration in the reclamation processes. In soils where large amounts of calcium carbonate are present, H_2SO_4 reacts in the following manner:

$$CaCO_3 + H_2SO_4 \longrightarrow CaSO_4 + H_2CO_3$$

$$H_2CO_3 \longrightarrow CO_2 + H_2O$$

Nor and Tabatabai (1977) reported very little pH change when a 200 ppm elemental S amendment was applied to an alkaline soil containing an inorganic C equivalent of 5.1 percent calcium carbonate.

Oxidation of elemental S has been shown to be directly related to soil pH (Attoe and Olson, 1966). Nor and Tabatabai (1977) observed the rates of oxidation of elemental S to $SO_4^=$ in acid soils to be lower than the oxidation rates in the alkaline soils. In a similar manner, Elkins and Ensminger (1971) reported that increasing the soil pH through the use of $CaCO_3$ resulted in large increases of $SO_4^=$ S in soil solutions.

The intent of this research was to evaluate the effect of sideband ing two sources and two levels of sulfur into selected tree nursury beds and evaluate the resulting effects upon (1) the hydrogen ion concentration (pH), (2) electrical conductivity (EC), and (3) the germination and growth of seedling production.

Materials and Methods

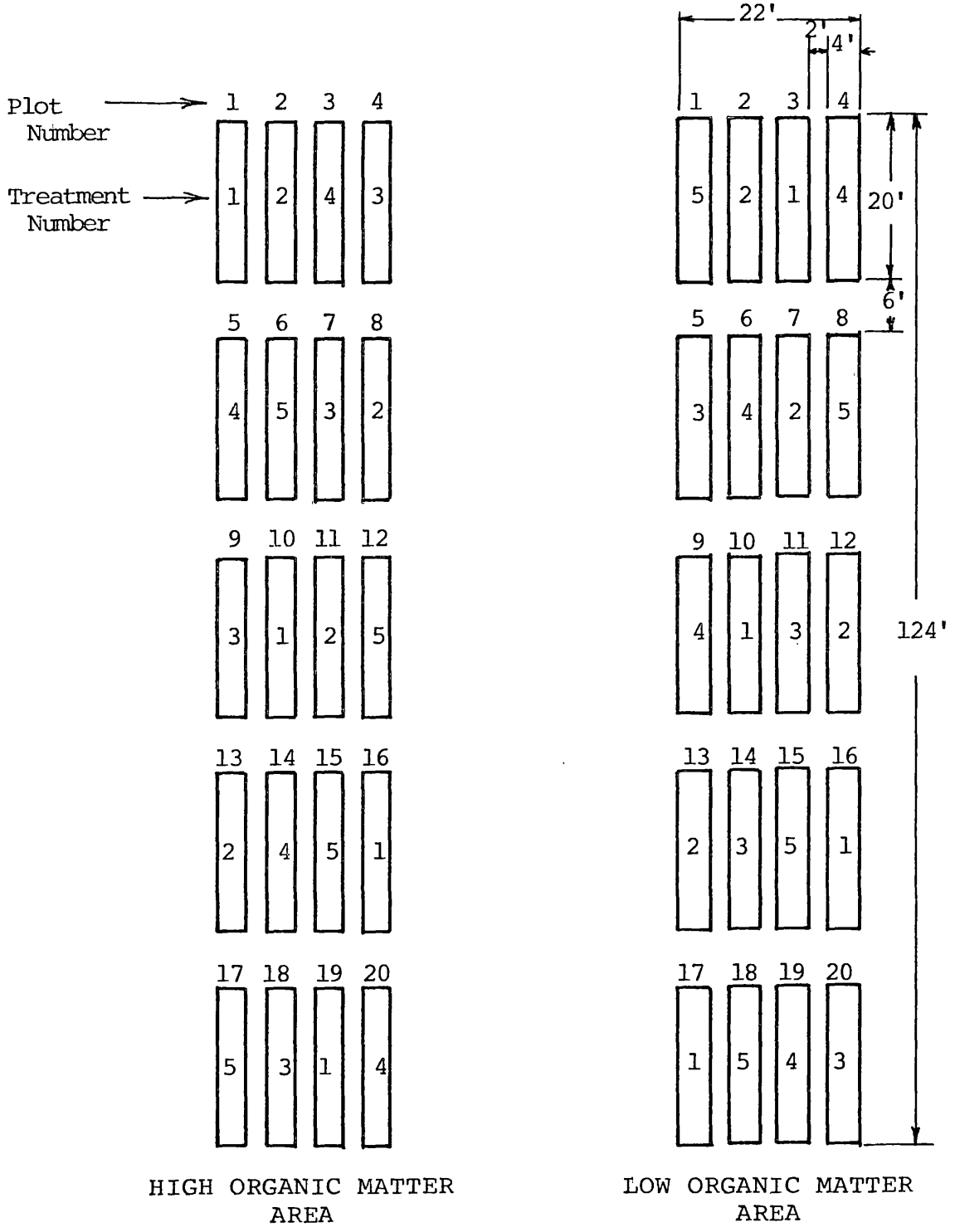
Two areas of the Albuquerque Tree Nursury were selected to represent study sites of a high and low organic matter concentration in the soil (Haas, 1983). Following a May, 1983 seeding by the tree nursury personnel, twenty 4' x 20' study plots were layed out in each area with a two foot buffer zone surrounding the perimeter of each plot. Two forms of sulfur at two rates, including a control, were randomly replicated four times in each organic matter area. FIGURE I depicts the field plot layout and the replication sequence of the amendments applied, with the sulfur forms applied and rates of application presented in TABLE I.

In each plot, seven bands were constructed adjacent to each seeding row for the sulfur placement. Spacing for each band was approximately two inches to the side of each seed row and two inches below the soil surface. This technique allowed a uniform distribution of sulfur amendment to be applied, while ensuring that seeds are not directly in contact with the sulfur.

The method of application varied with the form of sulfur applied. Presented below are descriptions for each amendment application, with rates applied on an equivalent per acre basis per plot.

> Agrisul is a granular, water degradable 95 percent active ingredient sulfur soil amendment uniformly weighed and applied into the bands of each required plot. Following treatment application, the amendment was covered with the soil taken out of the band to allow maximum soil contact with the sulfur granules, initiating oxidation (ILLUSTRATION 1).

> Microsul is a liquid flowable sulfur product that is 64 percent active ingredient. FIGURE II depicts a schematic diagram of the apparatus employed to



HIGH ORGANIC MATTER AREA

LOW ORGANIC MATTER AREA

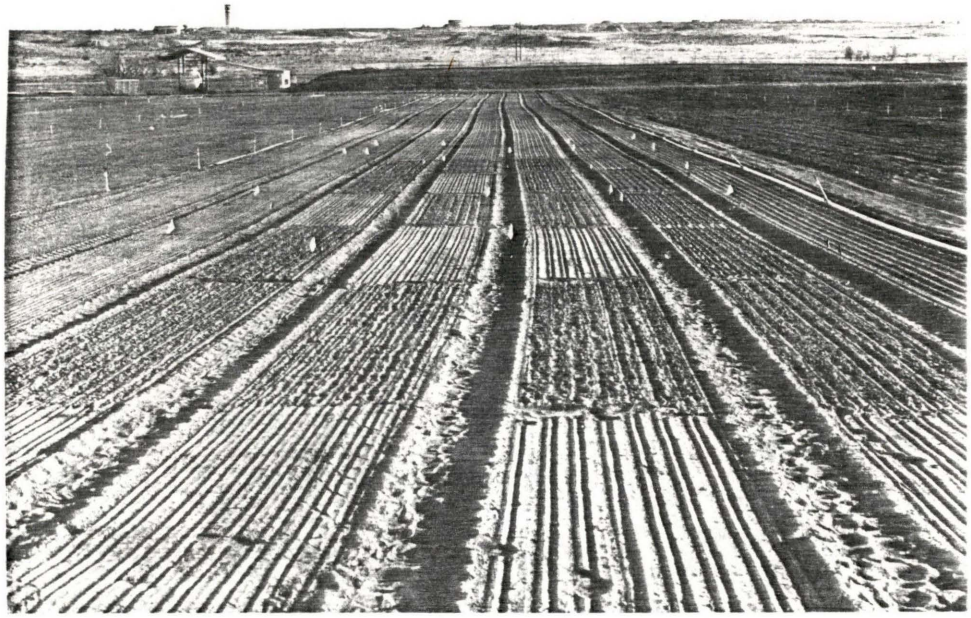
FIGURE I

LAYOUT OF STUDY PLOT RANDOMIZATION AND TREATMENTS FOR LOW AND HIGH ORGANIC MATTER AREAS

TABLE I

FORMS OF SULFUR APPLIED
AND APPLICATION RATES

Treatment Number	Form of Sulfur	Application Rate	Quantity Applied/plot	Quantity Applied/band
1	Microsul	1500 lbs S/ac.	.34 gal.	6.21 fl. oz.
2	Microsul	750 lbs S/ac.	.17 gal.	2.07 fl. oz.
3	Agrisul	1500 lbs S/ac.	2.84 lb.	.40 lb.
4	Agrisul	750 lbs S/ac.	1.42 lb.	.20 lb.
5	Control			



CONSTRUCTION OF BANDS

APPLICATION OF THE AGRISUL TREATMENT

ILLUSTRATION 1

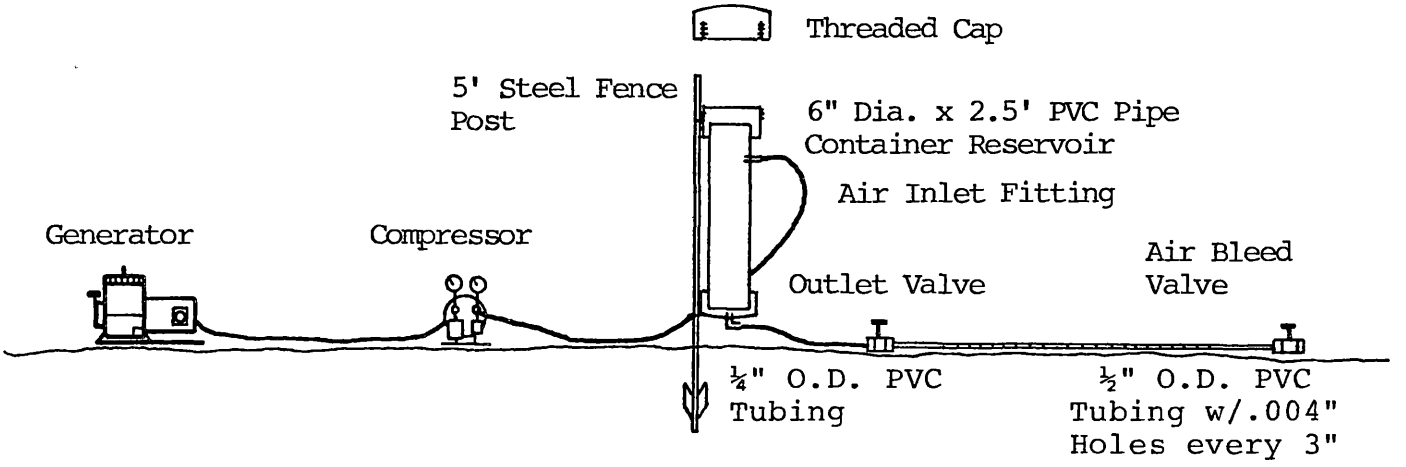


FIGURE II

SCHEMATIC DIAGRAM
APPARATUS TO DISPENSE MICROSUL

distribute the liquid, flowable Microsul. The measured rate of Microsul was poured from a sample bottle into a PVC reservoir container followed by two rinsings of distilled dionized water. The rinsings removed any amendment residues which may have remained in the sample bottles or on the sides of the PVC container. The container was then sealed and a pressure of approximately fifteen lb./sq. in. was generated internally. Upon pressure build-up, the Microsul amendment was then released into a ½ inch O.D. PVC tubing placed in the bottom of each band and uniformly exited through .004 inch diameter holes spaced at every three inches in the tubing material. The container reservoir was then rinsed twice with distilled water before moving to another band. Following amendment placement, the bands were then backfilled with soil used to construct the furrow bands. Approximately one gallon of distilled-dionized water was used as the carrying agent and for rinsing of the liquid residue for each of the Microsul field plot applications (ILLUSTRATION 2).

Upon seedling emergence, the initial germination response was performed during the last week in July, 1983. Sampling format for this parameter utilized a 1' x 4' frame which was randomly placed at five locations across each plot. A total count was made on all live seedlings rooted inside a 1' x 1' quadrat of the frame.

Seedling vigor was measured in September of 1983 and August and September of 1984. The methodology utilized for this parameter was to randomly select ten seedlings in each plot and record the height of each seedling. Measurements were taken from ground level to the tip of each terminal bud.

Measurements of the soil pH were performed on the saturated paste (U.S. Salinity Laboratory Staff, 1954) of three randomly selected sample sites in each plot at the three following depths: 0-4 inches, 4-8 inches, and 8-12 inches. Samples were collected in the space between the sulfur band and the seeding row. The dates of sample collection for this para-

TREATMENT INITIATION OF MICROSUL

MICROSUL APPLICATION INTO THE BAND

ILLUSTRATION 2

meter were July and September of 1983, and May, July, and September of 1984.

The extracted solution of the saturated paste was used to measure the electrical conductivity. Determinations of the soluble salt concentrations were performed only on samples taken from the 0-4 inch depth with data collections in September of 1983 and 1984.

The experimental design is a multi-factor split plot analysis of variance with repeated measurements in time. The functional structure of the models allow correlations between time, depth, treatment, and organic matter area interactions. The least significant difference (LSD) test was used to determine significant differences ($p = .01$) between treatment means.

RESULTS AND DISCUSSION

The addition of two sources at two rates of sulfur applied to a low and high organic matter study area was performed with the intent of reducing soil pH to improve quality and quantity of nursury tree production. In the presentation of the results for this report, only effects and interactions which were significant ($p = .01$) were discussed. The mean values of all effects and interactions for the germination, vigor, pH, and EC measurements not determined to be significant at this level, are presented in APPENDIX A, with the analysis of variance table for each parameter in APPENDIX B.

The results of the pH values for the treatment by depth interaction are presented in TABLE II and FIGURE III. The Microsul applications produced significantly lower pH values in the 0-4 inch depth than the Agrisul treatments and control, with the 1500 lb./ac. Microsul treatment producing the lowest value for pH. These results indicate the increased ability of Microsul to lower soil pH, at least in the first inches of the soil profile. Because the quantities of elemental S applied were identical for each given treatment rate, it appears that the conversion of S to H_2SO_4 is related to the rate of formation by each product. This conversion rate is strongly related to the form and particle size (McGeorge, 1945, and Attoe and Olson, 1966) of the sulfur applied. The Microsul amendment has a particle size of less than one micron and is in liquid flowable form. Conversely, Agrisul is in granular form with a particle size distribution of forty microns. The smaller micron-sized product allowed a larger surface to soil contact, initiating a faster and greater conversion of the elemental S. This agrees with the research by Ruehr (1977) and Li and Caldwell (1966), showing an increased rate of pH reduction from the smaller particle size S amendments.

TABLE II

PH VALUES FOR THE TREATMENT BY DEPTH INTERACTION

Treatment	Depth (in.)	pH Value
1500 lb./ac. Microsul	0-4	7.38 a[1]
750 lb./ac. Microsul	0-4	7.46 a b
1500 lb./ac. Microsul	8-12	7.49 a b c
750 lb./ac. Microsul	8-12	7.49 a b c
1500 lb./ac. Microsul	4-8	7.50 a b c
1500 lb./ac. Agrisul	8-12	7.52 a b c
750 lb./ac. Agrisul	8-12	7.52 a b c
750 lb./ac. Microsul	4-8	7.53 a b c
750 lb./ac. Agrisul	4-8	7.54 b c
1500 lb./ac. Agrisul	4-8	7.55 b c
Control	4-8	7.55 b c
Control	8-12	7.55 b c
750 lb./ac. Agrisul	0-4	7.56 b c
1500 lb./ac. Agrisul	0-4	7.58 c
Control	0-4	7.63 c

[1]Means with the same letter are not significantly different (p = .01) as determined by the least significant difference (LSD) test.

FIGURE III

TREATMENT VERSUS DEPTH INTERACTION
FOR THE pH PARAMETER

Of interest to the above, irrigation practices at the Albuquerque Tree Nursury do not appear to be sufficient to allow breakdown and solublization of the Agrisul granules applied. It was noted during the sampling periods that the Agrisul granules were still intact in the banding rows. Therefore, the results generated from this product, do not represent the actual sulfur oxidizing capabilities of this product to lower soil pH.

For both Agrisul treatments and control, the mean pH value of the 0-4 inch depth was higher than the 4-8 inch and 8-12 inch sections. Additionally, for all treatments but the 1500 lb./ac. Microsul treatment and control, the 8-12 inch depth recorded a pH value lower than the 4-8 inch soil depth. An explanation to this relates to the increased reactive properties of Microsul and the buffering capacities present in the soil. As depicted in FIGURE III, the rapid rate of Microsul to react with the buffering capacity of calcium carbonate ($CaCO_3$) to precipitate calcium sulfate ($CaSO_4$) and lower the soil pH is shown. However, through time and evaporation of the soluble salts to the surface, the Agrisul treatments which were not producing sufficient S into the soil solution, showed little or no effect of pH reduction. Concentrating the salts into the 0-4 inch depth through evaporation, accounted for very small amounts of S to be leached into the lower depths for oxidation. Consequently, the 4-8 inch and 8-12 inch depths exhibited little pH change.

The pH values of the three depths sampled for each period is presented in TABLE III, and graphically depicted in FIGURE IV. The mean pH values of each depth sampled in 1983 were significantly lower than the pH values of the 1984 sampling depths. The difference in pH values reported during this period may be attributed to the conversion of the large

TABLE III

PH VALUES FOR THE TIME BY DEPTH INTERACTION

Time	Depth (in.)	pH Mean
July, 1983	4-8	7.32 a
September, 1983	4-8	7.32 a
September, 1983	8-12	7.32 a
September, 1983	0-4	7.38 a
July, 1983	8-12	7.41 a b
July, 1983	0-4	7.42 b
September, 1984	0-4	7.54 c
July, 1984	0-4	7.60 c d
September, 1984	8-12	7.60 c d
July, 1984	8-12	7.61 c d e
May, 1984	8-12	7.63 d e f
July, 1984	4-8	7.66 d e f
September, 1984	4-8	7.67 e f
May, 1984	4-8	7.68 e f
May, 1984	0-4	7.68 e f

[1]Means with the same letter are not significantly different ($p = .01$) as determined by the least significant difference (LSD) test.

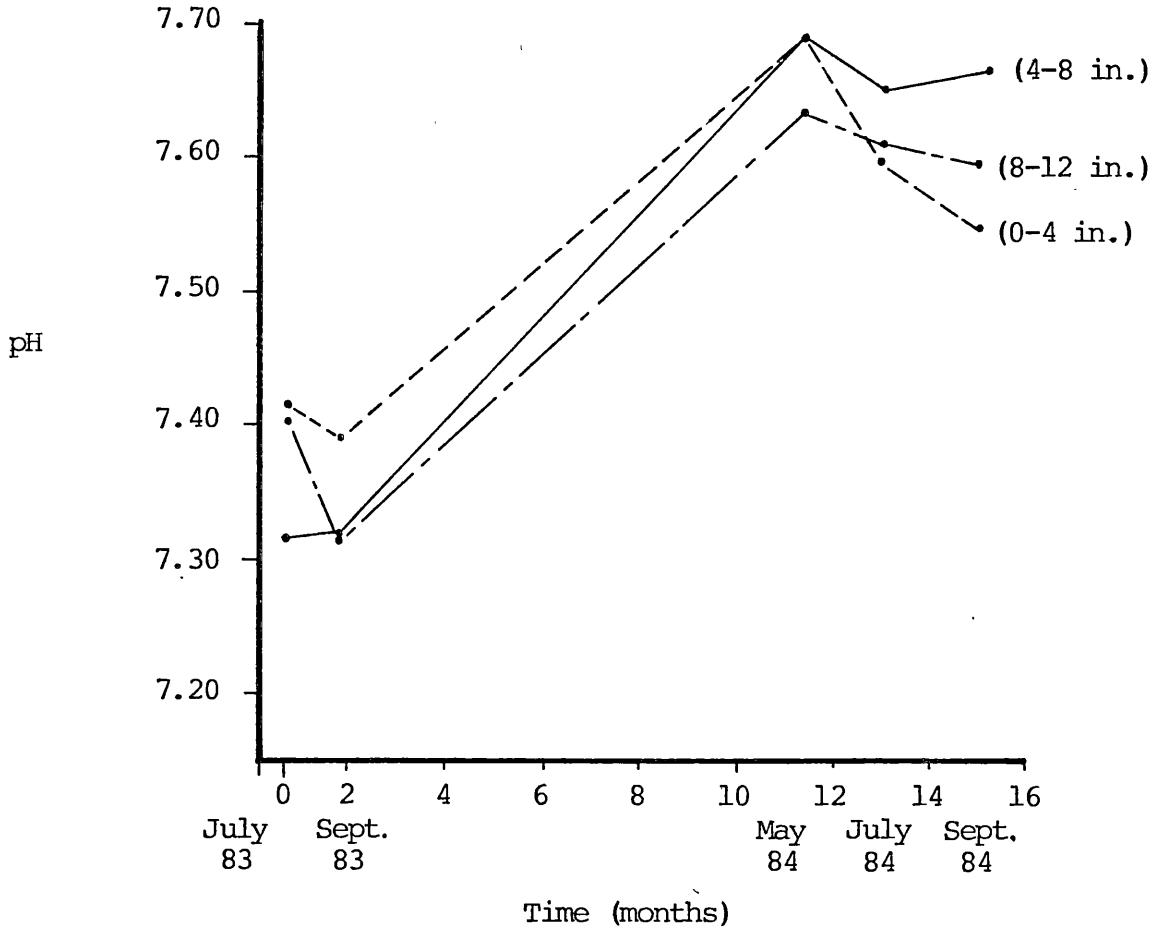


FIGURE IV

TIME VERSUS DEPTH INTERACTION
FOR THE pH PARAMETER

quantities of available S which were oxidized to H_2SO_4 during the first months of this study. The pH values of the 0-4 inch and 8-12 inch depths decreased from the July to September 1983 sampling periods. At this same time period, the 4-8 inch depth remained relatively constant. All depths recorded highest pH readings during the May 1984 sampling period. The higher recorded values are to be expected when considering the reduced microbial activity during the winter and early spring months when soil temperatures and moisture are low (Alexander, 1969, and Attoe and Olson, 1966). A decrease in soil pH during the 1984 sampling year was recorded for all depths. Although the 4-8 inch and 8-12 inch sections showed a decrease in soil pH over this period, the 0-4 inch depth recorded the lowest soil pH. This effect in the surface to 4 inch section is evidence of the conversion of S to H_2SO_4 by the treatments applied. Apparently not all of the S in the amendment had been tied up by the dominant cations in the soil. During the winter months the planting beds are kept moist generally to a depth of fourteen inches (Bates, 1985) by sprinkler irrigation and natural events. At this time, leaching of S can occur (Tisdale and Nelson, 1966, and Harward and Reisenauer, 1965) to lower depths of water percolation. The leaching of the S appears to have been carried to the water percolation depths (8-12 inches), and remain at the depth of highest S concentration, the 0-4 inch interval.

The rise in pH which occurs from the September, 1983, to May, 1984, sampling period also displays the high buffering capacities present in these soils. During this period of dormant microbial activity where the conversion of S to H_2SO_4 has decreased, the amount of $CaCO_3$ reacted upon is reduced. In addition, the increase in soluble cations and anions from chemical weathering and irrigation applications appear to have all contributed to the increase of soluble salts in the

soils and increase the soil pH.

The electrical conductivity (EC) measurements for the treatments and control are presented in TABLE IV. The EC values reported by the Microsul treated plots recorded the largest soluble salt concentrations, with the 1500 lb./ac. Microsul treatment responsible for the significantly largest EC value. During all field sampling collection periods, a white precipitate was observed on the soil surface of most Microsul field plots. This material in all liklihood was calcium sulfate ($CaSO_4$), and formed by the following reaction:

$$2CaCO_3 + H_2SO_4 \longrightarrow Ca(HCO_3) + CaSO_4$$

If it is assumed that the H_2SO_4 also reacts with the Ca present on the exchange sites, then the formation of $CaSO_4$ follows the reaction presented below:

$$CaX_2 + H_2SO_4 \longrightarrow 2HX + CaSO_4$$

The $CaSO_4$ diffuses to the soil surface during the drying part of the wet and dry cycles of the irrigations. The relationship between the precipitated $CaSO_4$ on the surface of the Microsul treatments, with no apparent precipitate on the surface of the Agrisul treatments, agrees with the previous discussion concerning the resistant nature of breakdown and insufficient irrigations applied to the Agrisul treated plots to initiate appreciable H_2SO_4 production. Although no significant differences were observed between the Agrisul treatments and control, the 1500 lb./ac. Agrisul treatment recorded the largest EC value, indicating the initiation of H_2SO_4 formation.

The September, 1983 sampling period recorded a significantly larger EC value mean than did the EC means of the 1984 sampling

TABLE IV

ELECTRICAL CONDUCTIVITY (EC) VALUE OF
THE 0-4 IN. SOIL DEPTH BASED UPON TREATMENT

Treatment Application	EC Value (mmhos/cm.)
1500 lb./ac. Microsul	2.77 a[1]
750 lb./ac. Microsul	2.39 b
1500 lb./ac. Agrisul	1.61 c
750 lb./ac. Agrisul	1.41 c
Control	1.35 c

[1]Means with the same letter are not significantly different ($p = .01$) as determined by the least significant difference (LSD) test.

period (TABLE V). The lower EC values reported in the last sampling year may indicate that the amount of S available for conversion to $CaSO_4$ is lower than the available S produced in 1983. In addition, leaching of the soluble salts may have occurred to a lower depth which was not sampled during this study.

TABLE VI presents the mean EC values for the time by treatment interactions. The ability of the Microsul treatments to release more S and at a faster rate than that released by the Agrisul treatments is illustrated in FIGURE V. Treatments were placed in the soil during the latter part of May, 1983. The mean values of the EC concentrations during the September, 1983 sampling period are highest for all treatments, particularly for the 1500 lb./ac. treatment. The decline in EC values reported during the September, 1984 sampling period for the Microsul treatments imply that the amount of S available for reaction has been reduced. Although this trend is observed for the Agrisul treatments, the interpretation is not as easily explained when considering that the Agrisul amendments were still observed in the banding rows. It is possible that breakdown and release of S in the Agrisul may be occurring at a much slower rate.

A significant difference existed in the heights of the trees (vigor) over time (TABLE VII). Growth of the tree seedlings increased over the thirteen month study period, with the August, 1983 measurement accounting for a statistically smaller mean for the height then the measurements taken in September of 1983 and 1984. Numerous investigators (McClean and Lint, 1916; Narrot and Ravikovitch, 1969; and Mortvedt, Giordano, and Lindsay, 1972) have reported that by decreasing the soil pH, the availability of certain micronutrients increases. A nutrient evaluation was not performed on the

TABLE V

ELECTRICAL CONDUCTIVITY (EC) VALUE OF
THE 0-4 IN. SOIL DEPTH BASED UPON SAMPLING TIME

Sampling Time	EC Value (mmhos/cm.)
September, 1983	2.50 a[1]
September, 1984	1.31 b

[1]Means with the same letter are not significantly different (p = .01) as determined by the least significant difference (LSD) test.

TABLE VI

ELECTRICAL CONDUCTIVITY (EC) VALUES FOR THE TIME BY TREATMENT INTERACTION

Treatment	Time	EC (mmhos/cm.)
1500 lb./ac. Microsul	September, 1983	3.15 a[1]
750 lb./ac. Microsul	September, 1983	2.59 a b
1500 lb./ac. Agrisul	September, 1983	2.52 a b c
Control	September, 1983	2.32 a b c d
750 lb./ac. Agrisul	September, 1983	2.04 a b c d
1500 lb./ac. Microsul	September, 1984	1.66 b c d
750 lb./ac. Microsul	September, 1984	1.60 b c d
1500 lb./ac. Agrisul	September, 1984	1.43 b c d
750 lb./ac. Agrisul	September, 1984	1.39 c d
Control	September, 1984	1.34 d

[1]Means with the same letter are not significantly different ($p = .01$) as determined by the least significant difference (LSD) test.

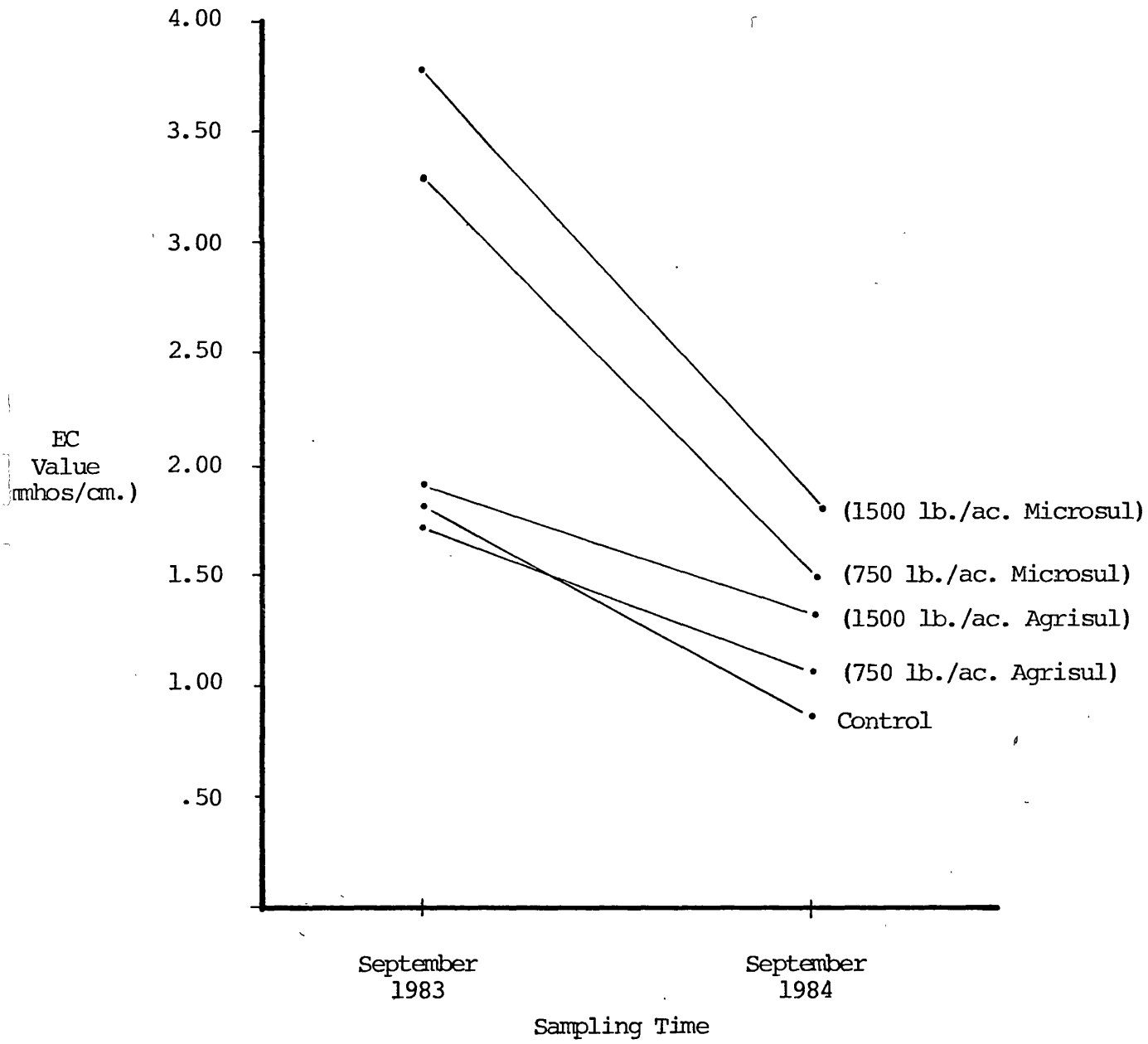


FIGURE V

TIME VERSUS TREATMENT INTERACTION
FOR THE EC PARAMETER

TABLE VII

VIGOR MEASUREMENT OF TREE
SEEDLINGS BASED UPON SAMPLING TIME

Sampling Time	Height (in cm.)
August, 1983	5.26 a[1]
September, 1983	8.50 b
September, 1984	9.27 b

[1]Means with the same letter are not significantly different ($p = .01$) as determined by the least significant difference (LSD) test.

soils or seedlings tissues during this study. It is, therefore not known whether the treatments produced an effect on nutrient uptake.

The mean values of the germination counts for each treatment and control are presented in TABLE VIII. Significant differences were observed between the germination means for the two treatments. The Microsul treated plots recorded lower mean seedling counts than the means of the Agrisul treated plots. Similarly, the number of germinating seedlings in each treatment was lower than the control seedling germination counts. These affects imply that the conversion of H_2SO_4 to $CaSO_4$ probably increased the osmotic potential of the soil solution and reduced the availability of water to the seed. The relationship between high EC values and decreased germination counts appear to be directly related to the source and rate of S applied.

During the seeding operation, a malfunction of the seeding machinery occurred, affecting seeding rates and depths to the low and high organic matter areas (Haas, 1983). An uneven planting pattern resulted in a highly variable distribution of seeds. The degree of error is not known, and therefore, the results of this particular parameter may be questionable.

TABLE VIII

TREATMENT EFFECTS UPON THE GERMINATION OF TREE SEEDLINGS

Treatments	Germination Count
1500 lb./ac. Microsul	107.50 a[1]
750 lb./ac. Microsul	112.13 a
1500 lb./ac. Agrisul	127.88 a b
750 lb./ac. Agrisul	150.75 b c
Control	167.13 c

[1]Means with the same letter are not significantly different ($p = .01$) as determined by the least significant difference (LSD) test.

CONCLUSIONS

The outcome of this study clearly shows that the Microsul applications were superior to the Agrisul treatments in reducing soil pH for the fifteen month period. This was especially true for the 1500 lb./ac. Microsul amendment, which also exhibited an increase rate of conversion. The presentation of results for pH by the Agrisul treatments may be misleading as irrigations applied to the study plots did not appear to be sufficient to allow complete solublization of this treatment. Similarly, evidence of $CaSO_4$ on the surface of the Microsul plots implies that irrigations were not leaching the soluble salt concentrations downward through the root zone. There appeared to be an initiation of H_2SO_4 production during the 1984 period from the Agrisul treatments, however, this amendment was still visible in the banding rows of the plots after two years. The pH values presented for this amendment give no real measure of the degree of sulfur oxidation under these soil and water conditions. It appears that several months may be required for complete breakdown of the Agrisul treatments.

The results of this study indicate that to completely evaluate the effects of these two sulfur treatments, additional data collections beyond the September, 1984 completion date is proposed. This longer time frame would generate additional data which would be more informative from a tree nursury management and production viewpoint.

The amount of $CaCO_3$ existing in the soils for this study was not determined. Therefore, no evaluation can be made as to the conversion by each treatment to precipitate $CaSO_4$ and reduce the soil pH. Although the Microsul treatments at both levels more effectively reacted with the $CaCO_3$ present, the buffering capacity was never determined. The present method

of determining the buffering capacities in soils, is to perform a calcium carbonate equivalence test and determine the amount of lime present. The results from this test will determine the amounts of amendment required to correct soils with high pH problems.

The results of the pH and EC measurements show that the Microsul applications do reduce soil pH in the surface soil layers. However, based upon these same results, treatments also reduced the number of germinating seedlings, with the Microsul applications recording the lowest seedling counts. The results of this parameter were probably influenced by the malfunction in the seedling operation resulting in an uneven distribution of seeds into the beds. As a result, the data may be suspect. Considering an equal adverse impact to all seeded plots, then treatments may indeed be affecting seed germination. Because seed germination is a critical factor in a tree nursury operation, the Agrisul products, due to their slow reaction rate, may offer a solution to the high pH problems and reduce the affect of seeding germination. However, the use of Agrisul and Microsul amendments warrants further study.

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APPENDIX A

Organic Matter Level Upon pH

High OML	7.53
Low OML	7.51

Treatment Effect Upon pH

1500 lb./ac. Microsul	7.45
750 lb./ac. Microsul	7.49
1500 lb./ac. Agrisul	7.54
750 lb./ac. Agrisul	7.55
Control	7.58

Time Effect Upon pH

6/83 Sampling Period	7.38
9/83 Sampling Period	7.34
5/84 Sampling Period	7.66
6/84 Sampling Period	7.62
9/84 Sampling Period	7.60

Depth Effect Upon pH

0-4 inches	7.52
4-8 inches	7.53
8-12 inches	7.51

Organic Matter Level x Treatment Interaction Upon pH

High OML x 1500 lb./ac. Microsul	7.47
High OML x 750 lb./ac. Microsul	7.50

High OML x 1500 lb./ac. Agrisul	7.56
High OML x 750 lb./ac. Agrisul	7.56
High OML x Control	7.57
Low OML x 1500 lb./ac. Microsul	7.44
Low OML x 750 lb./ac. Microsul	7.49
Low OML x 1500 lb./ac. Agrisul	7.52
Low OML x 750 lb./ac. Agrisul	7.53
Low OML x Control	7.59

Organic Matter Level x Time Interaction Upon pH

High OML x 6/83 Sampling Period	7.41
High OML x 9/83 Sampling Period	7.35
High OML x 5/84 Sampling Period	7.62
High OML x 6/84 Sampling Period	7.64
High OML x 9/84 Sampling Period	7.63
Low OML x 6/83 Sampling Period	7.35
Low OML x 9/83 Sampling Period	7.33
Low OML x 5/84 Sampling Period	7.67
Low OML x 6/84 Sampling Period	7.68
Low OML x 9/84 Sampling Period	7.58

Organic Matter Level x Depth Interaction Upon pH

High OML x 0-4 inches	7.54
High OML x 4-8 inches	7.54
High OML x 8-12 inches	7.52
Low OML x 0-4 inches	7.50
Low OML x 4-8 inches	7.52
Low OML x 8-12 inches	7.51

Treatment x Time Interaction Upon pH

1500 lb./ac. Microsul x 6/83 Sampling Period	7.33
1500 lb./ac. Microsul x 9/83 Sampling Period	7.31
1500 lb./ac. Microsul x 5/84 Sampling Period	7.57
1500 lb./ac. Microsul x 6/84 Sampling Period	7.52
1500 lb./ac. Microsul x 9/84 Sampling Period	7.54
750 lb./ac. Microsul x 6/83 Sampling Period	7.28
750 lb./ac. Microsul x 9/83 Sampling Period	7.31
750 lb./ac. Microsul x 5/84 Sampling Period	7.66
750 lb./ac. Microsul x 6/84 Sampling Period	7.60
750 lb./ac. Microsul x 9/84 Sampling Period	7.61
1500 lb./ac. Agrisul x 6/83 Sampling Period	7.42
1500 lb./ac. Agrisul x 9/83 Sampling Period	7.35
1500 lb./ac. Agrisul x 5/84 Sampling Period	7.70
1500 lb./ac. Agrisul x 6/84 Sampling Period	7.64
1500 lb./ac. Agrisul x 9/84 Sampling Period	7.58
750 lb./ac. Agrisul x 6/83 Sampling Period	7.41
750 lb./ac. Agrisul x 9/83 Sampling Period	7.36
750 lb./ac. Agrisul x 5/84 Sampling Period	7.69
750 lb./ac. Agrisul x 6/84 Sampling Period	7.64
750 lb./ac. Agrisul x 9/84 Sampling Period	7.63
Control x 6/83 Sampling Period	7.47
Control x 9/83 Sampling Period	7.36
Control x 5/84 Sampling Period	7.71
Control x 6/84 Sampling Period	7.70
Control x 9/84 Sampling Period	7.65

Organic Matter Level Effect Upon E.C. (mmhos/cm.)

High OML	2.00
Low OML	1.82

Treatment Effect Upon E.C. (mmhos/cm.)

1500 lb./ac. Microsul	2.78
750 lb./ac. Microsul	2.39
1500 lb./ac. Agrisul	1.61
750 lb./ac. Agrisul	1.41
Control	1.36

Time Effect Upon E.C. (mmhos/cm.)

9/83 Sampling Period	2.50
9/84 Sampling Period	1.31

Organic Matter Level x Treatment Interaction Upon E.C. (mmhos/cm.)

High OML x 1500 lb./ac. Microsul	3.05
High OML x 750 lb./ac. Microsul	2.40
High OML x 1500 lb./ac. Agrisul	1.62
High OML x 750 lb./ac. Agrisul	1.43
High OML x Control	1.49
Low OML x 1500 lb./ac. Microsul	2.50
Low OML x 750 lb./ac. Microsul	2.39
Low OML x 1500 lb./ac. Agrisul	1.59
Low OML x 750 lb./ac. Agrisul	1.39
Low OML x Control	1.21

Organic Matter Level x Time Interaction Upon E.C. (mmhos/cm.)

High OML x 9/83 Sampling Period	2.73
High OML x 9/84 Sampling Period	1.27
Low OML x 9/83 Sampling Period	2.28
Low OML x 9/84 Sampling Period	1.35

Treatments Effects Upon Seedling Vigor

Treatment	Mean (cm.)
1500 lb./ac. Microsul	7.02
750 lb./ac. Microsul	7.44
1500 lb./ac. Agrisul	7.75
750 lb./ac. Agrisul	7.89
Control	8.28

Organic Matter Level x Treatment Interaction
Upon Seedling Vigor

	Mean (cm.)
High OML x 1500 lb./ac. Microsul	7.36
High OML x 750 lb./ac. Microsul	8.41
High OML x 1500 lb./ac. Agrisul	7.99
High OML x 750 lb./ac. Agrisul	8.96
High OML x Control	8.29
Low OML x 1500 lb./ac. Microsul	6.68
Low OML x 750 lb./ac. Microsul	6.46
Low OML x 1500 lb./ac. Agrisul	6.81
Low OML x 750 lb./ac. Agrisul	7.50
Low OML x Control	8.27

Organic Matter Level x Time Interaction
Upon Seedling Vigor

	Mean (cm.)
High OML x 8/83 Sampling Period	5.22

High OML x 9/83 Sampling Period	9.23
High OML x 9/84 Sampling Period	10.16
Low OML x 8/83 Sampling Period	5.30
Low OML x 9/83 Sampling Period	7.76
Low OML x 9/84 Sampling Period	8.38

Treatment x Time Interaction Upon Seedling Vigor

1500 lb./ac. Microsul x 8/83 Sampling Period	5.07
1500 lb./ac. Microsul x 9/83 Sampling Period	7.57
1500 lb./ac. Microsul x 9/84 Sampling Period	8.42
750 lb./ac. Microsul x 8/83 Sampling Period	5.46
750 lb./ac. Microsul x 9/83 Sampling Period	8.07
750 lb./ac. Microsul x 9/84 Sampling Period	8.77
1500 lb./ac. Agrisul x 8/83 Sampling Period	5.06
1500 lb./ac. Agrisul x 9/83 Sampling Period	8.57
1500 lb./ac. Agrisul x 9/84 Sampling Period	9.61
750 lb./ac. Agrisul x 8/83 Sampling Period	5.36
750 lb./ac. Agrisul x 9/83 Sampling Period	8.82
750 lb./ac. Agrisul x 9/84 Sampling Period	9.48
Control x 8/83 Sampling Period	5.34
Control x 9/83 Sampling Period	9.45
Control x 9/84 Sampling Period	10.05

APPENDIX B

ANOVA FOR pH MEASUREMENT

SOURCE	DF	SS	MS	F
OML	1	0.1505	0.1505	3.12
TRT	4	3.4025	0.8506	17.68
OML x TRT (a)	4	0.1924	0.0481	
DEPTH	2	0.0862	0.0431	0.95
TRT x DEPTH	8	2.0683	0.2585	5.70**
ERROR (b)	10	0.4528	0.0453	
TIME	4	31.8982	7.9745	53.60
OML x TIME (c)	4	0.5951	0.1488	
TRT x TIME	16	1.1492	0.0718	1.21
OML x TIME x TRT (d)	16	0.9461	0.0591	
DEPTH x TIME	8	2.3293	0.2912	7.18**
DEPTH x TRT x TIME	32	1.3393	0.0419	1.03
ERROR (e)	40	1.6219	0.0405	
TOTAL	149	46.2318		

**Significant at the 0.01 level

ANOVA FOR ELECTRICAL CONDUCTIVITY MEASUREMENT

SOURCE	DF	SS	MS	F
OML	1	19,332.15	19,332.15	3.01
TRT	4	783,394.19	195,848.55	30.48**
OML x TRT (a)	4	25,700.31	6,425.08	
TIME	1	852,756.82	852,756.82	91.70**
TIME x TRT	4	213,396.89	53,349.22	5.74
ERROR (b)	5	46,495.29	9,299.06	
TOTAL	19	1,941,075.65		

**Significant at the 0.01 level

ANOVA FOR VIGOR MEASUREMENT

SOURCE	DF	SS	MS	F
OML	1	335,703.4	335,703.4	6.33
TRT	4	216,339.6	54,084.9	1.02
OML x TRT (a)	4	211,962.1	52,990.5	
TIME	2	3,623,682.4	1811,841.2	54.03**
TIME x TRT	8	98,162.5	12,270.3	0.36
ERROR (b)	10	335,356.2	33,535.6	
TOTAL	29	4,821,206.2		

**Significant at the 0.01 level

ANOVA FOR GERMINATION MEASUREMENT

SOURCE	DF	SS	MS	F
OML	1	378.12	378.12	1.61
TRT	4	1,740.50	435.13	7.42**
TRT x CONTROL	1	2,898.51	2,898.51	12.34**
OML x TRT	4	166.53	41.63	.71
TOTAL	10	5,183.66		

**Significant at the 0.01 level